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TECHNICAL REPORT ARPAD-TR-83004

**OBJECTIVE TECHNIQUES AND INSTRUMENTATION FOR THE
INSPECTION OF FIRE CONTROL SYSTEMS**

JOHN SALERNO

JANUARY 1984



**U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
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18. SUPPLEMENTARY NOTES This project has been accomplished as part of the U.S. Army's Manufacturing Testing Technology Program, which has for its objective the timely establishment of testing techniques, procedures, and prototype equipment (in mechanical, chemical, and nondestructive testing) to ensure efficient inspection methods for material/ <u>material procured and maintained by DARCOM.</u>		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Optical transfer function (OTF) Finite conjugate Modulation transfer function (MTF) Infinite conjugate Mercury ARC Resolution Tungsten halogen Afocal Xenon MTT-Image quality		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Currently, the image quality of optical instruments is assessed by human observers and resolution targets. This technique creates problems because it is subjective and may cause disputes in borderline situations. An alternative method that would yield an objective evaluation was considered necessary to avoid the problems associated with standard resolution charts. A program was established to evaluate the modulation transfer function (MTF) of the U.S. Army issue binocular model M19. The MTF of the instruments and the resolution measurements (cont)		

20. ABSTRACT (cont)

were to be compared in an attempt to correlate the results. Initial findings, together with the results from a similar project conducted in the United Kingdom, showed that no correlation existed between the two test methods. The possible explanation for this result is that the human observer is coherently coupled to the optical instrument and the eye, as part of the optical system, can compensate for aberrations within the instrument under test. For this reason the MTF was not considered a viable alternative to the present method of using a human observer and resolution targets.

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INTRODUCTION

This project involved the development of an objective technique and instrumentation for determining the resolution performance of fire control systems. The goal was to replace the current Air Force resolution charts, which depend on human interpretation, to make an accept or reject decision. A program was designed and executed to compare the modulation transfer function (MTF) of optical systems, using a Tropel Model 2000 optical transfer function (OTF) lens testing system, to resolution measurements acquired by means of resolution charts. The intent of this program was to establish a correlation between the two methods. Ten M19 binoculars, obtained on loan, were used in an attempt to demonstrate MTF as a viable alternative to resolution. It was anticipated that this technique would replace resolution measurements which are subjective in their nature.

DISCUSSION

The Tropel Model 2000 OTF lens testing system is a versatile and flexible instrument which can be adapted to any lens testing need and easily modified if test requirements change. The model 2000 can measure the imagery of almost any optical or electro-optical system by using a knife-edge scanning principle. This technique permits the use of the same scanner for ultraviolet (UV) visible and infrared (IR) image evaluation. The light source provides an intense and uniform point source of light for finite or, with collimator, infinite conjugate testing. Mercury arc, tungsten halogen, or xenon lamps are available to cover a wide range of spectral regions from ultraviolet to near infrared.

A measurement technique for the assessment of the image quality of the binoculars was developed and is currently on line. (Parameters are listed in appendix A.) However, the MTF results obtained by the new technique did not correlate with standard tests which creates the potential problem of rejecting optical instruments that are visually acceptable for use in the field. After our investigation, we became aware of a similar project, conducted in the United Kingdom, which measured the MTF of 25 binoculars and concluded that the measurements demonstrated no correlation with the resolution of the instruments (app B).

The reasons for the above results are not clearly understood; a possible explanation for the lack of agreement is that the eye is able to interact coherently with optical systems in such a way as to degrade, as well as improve, performance. Aberrations in the optical system couple coherently with those in the eye so that small errors of focus or of other aberrations in either the eye or the optical system may become mutually minimized in the overall interaction. Afocal instruments for visual use are designed for a detection system that is not only dynamic but is also comprehensively self-adaptive.

CONCLUSIONS

The next generation of Army projectiles for tank and artillery systems is more than likely to possess a fire-and-forget capability. Producing these rounds with the highest possible reliability while holding down the cost is the challenge we must meet. Target detection and recognition are of primary importance for these munitions, and it is in this area where modulation transfer function (MTF) can yield the greatest potential benefit. The MTF of a system can be used to help design and inspect lens parameters to match detector response when the detector is a device other than the human eye. One of the greatest advantages of using transfer functions is that of cascading system elements which permits the lens transfer function to be combined with that of the detector. Specifying the MTF in these situations can then yield the required performance at minimum cost by eliminating unnecessary specifications and overdesign of the detector lens combinations. It is in this application, where the detector is not the human eye but an electro-optical system, that the results of this project can be successfully applied and implemented. The MTF equipment is currently being used for unique testing to aid in the design/inspection/specification of new equipment under development for use in opto-electric fire control instruments or systems.

The purpose of the MTF to develop and to setup an objective measurement technique for the assessment of the image quality was concluded successfully; however, the task to establish a correlation between MTF and visual resolution (as determined by the human eye) was not accomplished. Measuring the MTF of an instrument is a powerful analytical tool for understanding which parameters affect the image quality of the optical instrument. However, the instrument interaction with the eye is complex and not well understood. It appears that the eye combined with visual image interpretation has the ability to tolerate some aberrations while possibly degrading others. This relationship causes poor correlation with the MTF results and the visual optical instruments used in the field. To have implemented the results of this work on visible light optical systems would have meant the rejection (by means of MTF measurements) of optical instruments that are acceptable to the human eye.

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APPENDIX A
TEST PARAMETERS

The test conditions for the M19 binocular (using Tropel verification lens as imager) are as follows:

$$\text{Exit pupil DIA M19} = 7 \text{ mm}$$

$$\text{Effective f/no. of imager lens} = \frac{75 \text{ mm}}{7 \text{ mm}} = 10.7 \text{ mm}$$

$$\begin{aligned} D (\text{airy disc}) &= 2.44 \times \lambda \times 10.7 \\ &= 2.44 \times 0.5 \times 10.7 \\ &= 13.05 \text{ } \mu\text{m} \end{aligned}$$

$$(\text{want 10 points of sample in } D): \quad \text{SS} = 1.3 \text{ } \mu\text{m}$$

With fishtail scan (which provides both tangential and sagittal scans), the scan edge velocity = $20 \text{ } \mu\text{m/sec} \times \cos 45^\circ$

$$= 14.14 \text{ } \mu\text{m/sec}$$

$$\text{sampling rate} = \frac{14.14 \text{ } \mu\text{m/sec}}{1.3 \text{ } \mu\text{m}} = 1088 \text{ hz}$$

$$\text{To determine CD, } \text{CD} = \frac{2400 \text{ hz}}{10.88 \text{ hz}} = 220.588 \approx 221$$

$$\text{Using NS} = 128, \text{ total scant length} = 128 \times 1.3 \text{ } \mu\text{m} = 166.4 \text{ } \mu\text{m}$$

$$f(\text{sf}) (\text{cut off}) = \frac{1}{\lambda \times 10.7} = \frac{1}{0.5 \times 10.7} = 186.9 \text{ Lp/mm}$$

$$f(\text{hz}) (\text{cut off}) = f(\text{sf}) \times \text{scan velocity}$$

$$= 186.9 \text{ Lp/mm} \times 14.14 \text{ } \mu\text{m/sec} \times \frac{1 \text{ mm}}{1000 \text{ } \mu\text{m}}$$

$$= 2.643 \text{ hz}$$

$$\begin{aligned} \text{FI} &= \frac{(60,000) (2400) (M)}{(\text{REV}) (R) (\cos \phi) (N) (\text{CD})} \\ &= \frac{(60,000) (2400) (1)}{(40 \text{ } \mu\text{m/rev}) (30 \text{ rev/min}) (0.707) (128) (221)} \\ &= 6 \text{ Lp/mm} \end{aligned}$$

where

M = magnification of relay lens
R = rpm of scanner motor
 ϕ = angle of tilt of scanner box
N = number of samples (NS)
CD = integer number
2400 = clock frequency
Rev = scan travel (microns/rev)

FI has to be converted back to angular resolution for afocal telescope system.

Angular resolution = spatial resolution x focal length of imager.

$$FI \text{ (angular)} = 6 \text{ Lp/mm} \times \frac{75 \text{ mm}}{1000}$$

$$0.45 \text{ LP/MRAD}$$

Pin hole size consideration

$$\text{Total magnification} = 1/10 \times 7 \times \frac{f_{\text{imager}}}{f_{\text{para}}}$$

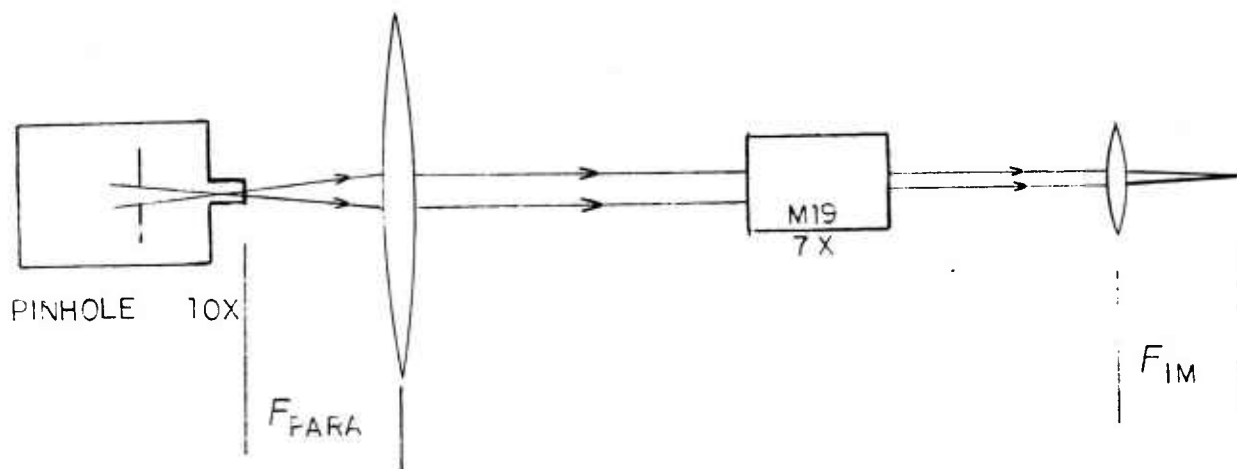
$$10\times \text{ relay lens} = 1/10 \times 7 \times \frac{75}{40 \times 25.4}$$

$$= 0.0516732$$

$$D \text{ (airy disk)} = 13 \text{ } \mu\text{m}$$

$$\text{Pinhole size at scanning plain} = 13/5 = 2.6 \text{ } \mu\text{m}$$

$$\text{Pinhole to be used} = \frac{2.6 \text{ } \mu\text{m}}{0.0516732} \approx 50 \text{ } \mu\text{m}$$



PD correction can be entered and is

$$50 \text{ } \mu\text{m} \times 0.0516732 =$$

$$2.58366 \text{ } \mu\text{m} \text{ has to be entered in mm} = 0.00258366$$

APPENDIX B

SIGHT UNIT INFANTRY TRILUX QAD(W) RESOLUTION AND MTF READINGS

<u>Serial no.</u>	<u>Resolution (s/arc)</u>	<u>Modulation transfer function (MTF) (10 cyc/deg)</u>		
		<u>on axis (%)</u>	<u>+2.8° off axis (%)</u>	<u>-2.8° off axis (%)</u>
039937	12.3	89	20	43
38	10.0	92	28	25
39	11.1	87	20	35
40	11.1	90	33	20
41	13.7	85	21	28
42	16.9	78	23	0
43	11.1	85	23	33
44	13.7	85	24	28
45	11.1	72	20	21
46	10.0	86	27	20
47	10.0	85	23	20
48	10.0	83	20	22
49	9.0	91	31	22
50	12.3	86	24	20
51	10.0	86	51	23
52	12.3	82	33	45
53	11.1	82	22	19
54	11.1	87	24	20
55	12.3	77	31	16
56	10.0	88	20	35
57	13.7	78	26	31
58	11.1	85	22	20
59	9.0	81	24	27
60	12.3	79	23	15
61	10.0	84	38	41
62	10.0	84	19	25
63	15.2	72	30	26
64	10.0	88	20	41
65	11.1	87	39	44
66	9.0	88	23	23
040514	11.1	80	34	17
15	12.3	76	21	16
16	12.3	75	18	21
17	15.2	72	44	17
18	15.2	76	18	20
19	11.1	79	17	19
20	12.3	80	26	18
21	13.7	56	19	22
22	16.9	72	21	22
23	11.1	81	23	24
24	11.1	80	19	20
25	12.3	73	28	20
26	10.0	80	29	18
27	9.0	82	25	19

(cont)

Serial no.	Resolution (s/arc)	Modulation transfer function (MTF) (10 cyc/deg)		
		on axis (%)	+2.8° off axis (%)	-2.8° off axis (%)
040528	11.1	84	21	16
29	13.7	73	19	33
30	10.0	84	22	23
31	13.7	68	26	21
32	12.3	79	25	29
33	16.9	39	18	30
34	11.1	72	19	38
35	11.1	78	20	29
36	10.0	82	20	28
37	10.0	79	29	18
38	13.7	59	18	16
39	10.0	83	19	21
40	12.3	78	34	12
41	13.7	68	19	25
42	10.0	83	31	18
43	9.0	91	14	44
041197	11.1	89	35	24
98	9.0	84	28	19
99	10.0	86	34	17
041200	11.1	80	31	23
1	10.0	89	34	20
2	6.5	79	24	25
3	8.1	90	18	27
4	12.3	83	22	18
5	9.0	82	22	27
6	11.1	88	23	19
7	11.1	84	27	16
8	11.1	85	21	22
9	10.0	91	21	27
10	10.0	88	35	18
11	9.0	87	20	32
12	15.2	74	23	23
13	10.0	82	17	22
14	10.0	88	21	18
15	11.1	82	21	21
16	13.7	88	22	18
17	10.0	80	18	16
18	9.0	84	19	22
19	9.0	86	18	21
20	10.0	90	27	20
21	11.1	92	34	18
22	11.1	Not tested	Not tested	Not tested
23	9.0	92	29	21
24	13.7	50	22	17
25	13.7	66	22	16
26	9.0	91	27	20

GLOSSARY

MG	magnification of the image at knife blade
NS	number of data points taken per scan
RP	related to the rpm of the scanner motor
CD	number of 2400-hz clock cycles between data samples
SS	distance in microns between two successive data points
FI	frequency increment of the printout (cycles/mm)

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